

Frequency and Temperature Dependence of the Dielectric Properties of Apple Juice at Microwave Frequencies

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(Received on: June 21, 2013)

ABSTRACT

The complex permittivity values of fresh juice of two cultivars of apple, viz., red delicious apple and Kashmiri apple were measured, in terms of the dielectric constant (ϵ') and dielectric loss factor (ϵ''), over the frequency range from 1GHz to 50 GHz and temperatures ranging from 30⁰C to 70⁰C, using the PNA network analyzer and open ended coaxial line probe technique. Both ϵ' and ϵ'' are found to depend on frequency and temperature. It was observed that as the frequency increases from 1 GHz to 50 GHz, ϵ' increases for first few GHz and then decreases with frequency and curves at different temperature narrow down for red delicious apple, whereas they almost merge with each other at about 45 GHz for Kashmiri apple. ϵ'' on the other hand increases with frequency and these curves at different temperatures become almost flat at higher frequencies, the curve for higher temperature being above the other curves, showing greater losses at higher temperatures.

Keywords: Apple, dielectric constant, dielectric loss factor, frequency, temperature.

INTRODUCTION

Dielectric properties of agricultural materials and their products are finding increasing applications as new technology in related food industries. Killing of insects in fruits, protection of seeds from insects through selective microwave heating,

measurement of moisture level in crops by using moisture meter for their safe storage and use of microwave cookers and ovens in home appliances area few such applications¹. Interaction between a food product and microwave energy is governed by the relative complex permittivity ($\epsilon^* = \epsilon' - j \epsilon''$) of the product. The real component of the

complex permittivity (ϵ' , known as the dielectric constant) is related to the energy storage in the material, and the imaginary component (ϵ'' , the loss factor) is related to the energy dissipation in the dielectric medium.

In connection with quality sensing of fruits and vegetables, the dielectric properties of twenty three kinds of common fresh fruits and vegetables were investigated² over the frequency range from 200 MHz to 20 GHz at 23° C by employing a network analyzer and coaxial probe. Dielectric properties of commercial apple juice product were also measured³ over the frequency range 200-MHz to 20-GHz frequency range and reported that the temperature dependence of apple juice at higher frequencies is very similar to that of pure liquid water.

However, reliable dielectric data on the dielectric properties of different cultivars of apple over the frequency range up to 50 GHz is not yet available in literature. Moreover, the knowledge of frequency and temperature dependence of dielectric properties of food materials is important as it provides useful information for processing, treatment and storage of food products, the sustenance of food values at higher temperatures and on exposure to EM radiation in different frequency range. The objective of the present research is to study the frequency dependence (1 to 50 GHz) and temperature dependence (30 to 70°C) of the dielectric properties of fresh juice of two cultivars of apple, viz., (i) Red delicious apple and (ii) Kashmiri apple, by using E8364C PNA network analyzer with open ended coaxial probe.

MATERIALS

Fresh samples of two cultivars of apple as needed for the present research were obtained from the local super market. For experimental study, the juice of the two cultivars was extracted by using a juicer and filtered by using a fine grain filter paper. The two cultivars selected for the present study are: Red delicious apple and Kashmiri apple.

EXPERIMENTAL METHOD

The dielectric constant (ϵ') and loss factor (ϵ'') of the fresh juice of two cultivars of apple were measured by using a E8364C PNA network analyzer in the frequency range 1 GHz to 50 GHz. The test probe consisted of an open ended coaxial probe system (HP85070B). The system software calculated the dielectric parameters from the phase and amplitude of the reflected signal at the interface between the open-ended coaxial line and the sample to be analyzed. Sample temperature control was provided by circulating cold / hot water through the jacket surrounding the sample cup from a Haake B3 Constant Temperature Circulator with a digital control module.

RESULTS AND DISCUSSION

The frequency dependence of the dielectric properties of the two samples of apple under consideration at different temperatures is shown in Figures 1 to 2. It is observed from Fig. 1 that in the frequency range 1 to 50 GHz, dielectric constant (ϵ') at any particular frequency increases with temperature. At a frequency of about 2.5 GHz the dielectric constant has a maximum value for all the temperatures ranging from 30°C to 70°C and therefore a peak in ϵ' –f

curve is obtained near about this frequency. At frequencies above 2.5 GHz, the diagram shows a decreasing trend of ϵ' with increasing frequency at all the temperatures. Water is the major contributor to the dielectric properties at microwave frequencies in foods. When we provide heat to food material, the solid material shrinks, and the water penetrates more and more in the pores and capillaries of the sample and some fraction of water also gets evaporated. When the water content becomes comparatively smaller, water is more tightly bound in molecular mono and multi-molecular layers⁴ which may be considered as the possible reason for increase in ϵ' with temperature. When frequency of microwaves is increased, the phase lag between the electromagnetic field and induced molecular vibrations may cause greater losses of energy, with the result ϵ' decreases and ϵ'' increases with increase in frequency, as apparent from Fig. 1 & 2. At high frequencies, such as 50 GHz, ϵ' -f curves for all temperatures almost merge

with each other, showing that at higher frequencies the effect of temperature variation (in the range 30°C to 70°C) is dominated by the effect of polarization, whereas ϵ'' -f curve show almost saturated behavior in this frequency range. Dielectric loss factor (ϵ'') first increases with increasing frequency, reaches at a maximum value and then remains almost uniform. The relaxation frequency of fresh fruits lies well above the frequency of 2.45 GHz but lower than the relaxation frequency of water⁵, which is 17.11 GHz at 20°C and the relaxation frequency also shift with increasing temperature towards the higher side⁶. We can therefore say that maximum values of dielectric loss factor are found where the relaxation frequency and the operating frequency are close to each other which may be considered to be around 15 to 20 GHz in the present case, losses at higher frequencies being almost of the same order for the both cultivars in the present case. Similar observations are obtained for the other cultivar of apple as apparent from Fig 2.

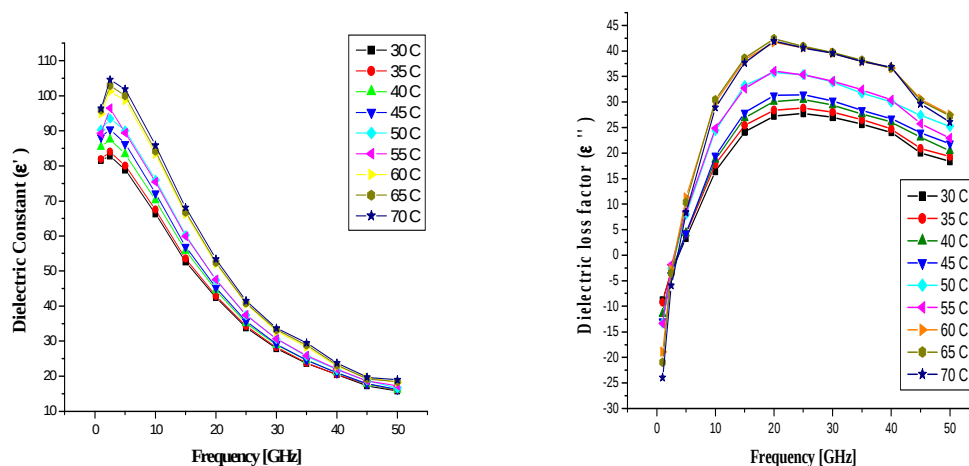


Figure 1: Frequency dependence of the dielectric properties of juice of Red delicious apple at indicated temperatures.

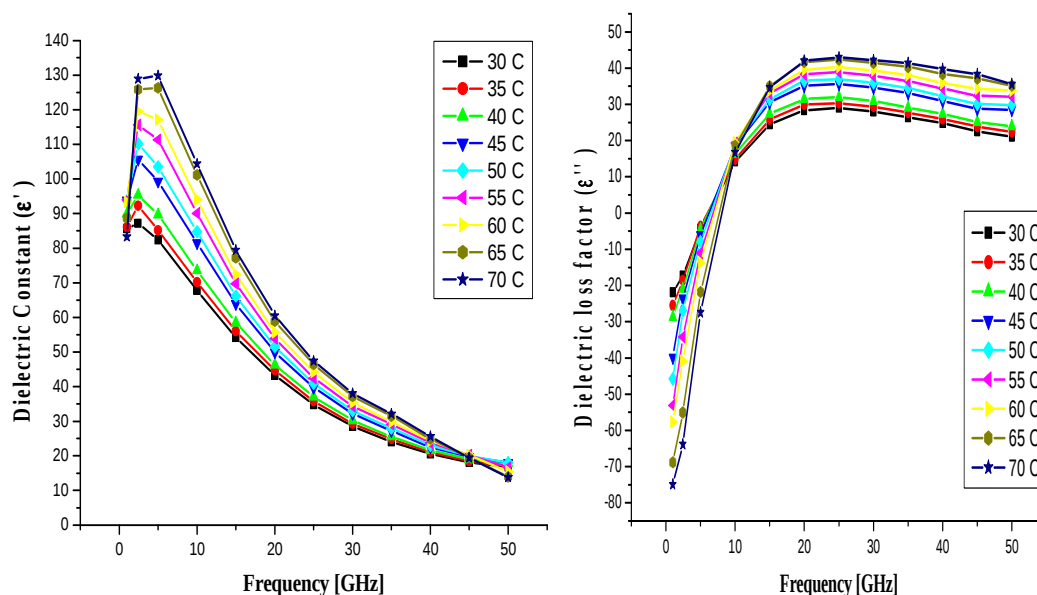


Figure 2: Frequency dependence of the dielectric properties of juice of Kashmiri apple at indicated temperatures.

CONCLUSIONS

The frequency and temperature dependence of the dielectric properties of fresh juice of two cultivars of apple have been efficiently measured with an open-ended coaxial-line probe, network analyzer, and a suitable sample temperature control equipment. The temperature and frequency dependence of the dielectric properties (ϵ' and ϵ'') forms a useful data for fruits, which may be used as a guide in processing and preservation of fruits and their products. ϵ' is found to have maximum value at about 2.5 GHz for both the cultivars of apple and there after decreases continuously up to 50 GHz. Water is major constituent of fruit juices, therefore we may expect a resonant frequency of the molecules of juices to occur at about 2.5 GHz.

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